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Light-weight highly porous building bricks from sawdust

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ABSTRACT

The saw or wood dust is a hazardous by-product resulting from cutting, grinding, drilling, sanding, or otherwise pulverizing wood or any with a saw. It causes many environmental and health hazards. So, the main target of this study is the utilization of this waste material in the production of light-weight building bricks. The ceramic and mechanical properties of the different batches containing various ratios of the sawdust were investigated. The results show that the addition of sawdust enhances the mechanical properties. Also, the incorporation of Al_2O_3 supported the consistence of new alumina silicate phases which could be responsible for the improving of the strength. The compressive strength increased with sawdust content up to 12 wt. % particularly with the increase of soaking time after firing and then decreased with the addition of 16 wt. % sawdust. The texture and conformity of pores in the best brick batch fired at 1000 ºC for 3 hours were observed by X-ray diffraction patterns (XRD) and scanning electron microscopy (SEM), respectively.

Keywords: Sawdust, clay, Ceramic parameters, Strength, XRD, SEM.

1. INTRODUCTION

Sawdust or wood dust is tiny or very fine particles of wood that are formed from sawing or sanding wood using a saw in cutting. Sawdust is an industrial by-product from cutting, grinding, drilling, sanding, or otherwise pulverizing wood using a saw or any other similar tool (Figure 1). It represents a hazard especially in terms of its flammability and it is also the main component of the particle board wood industry [1].

Figure 1 The sawdust sample

Scope of the problem

The get rid of sawdust waste is a great problem of rising interest to wood industries. Enormous quantities of sawdust are produced annually by sawmills. The sawdust produced in cutting a thousand board feet of 1 inch hard timber with a saw cutting machine, a 1/4 inch kerf is at least (0.25 / 12) x 1000 = 20.8 cubic feet (28.31 cubic meter) of solid wood. At a typical green weight of 23.6 kg per cubic foot for solid hardwood. This amount of sawdust would weigh 492.15 kg. The 12 % moisture content which is the same air-dry wood would weigh 36 kg /ft^3. Hence, the sawdust would weigh 340.19kg when dried to 12 % moisture content. All wood industries often lead to huge residues, where the wood mill produces about 272.16 kg of dry residues per thousand board feet [1,2]. So, the total amount of air-dry wood dust from wood industries in U.S.A. alone is more than 15 million tons yearly which enough to make a pile of 15.24 m high, 30.48m wide, and over 241.4 km long.

Uses of sawdust

The major use of sawdust is for particleboard. The coarse sawdust can be used as wood pulps. The sawdust can be practically used as an alternative to clay and/or a fuel. Furthermore, it can be used to keep ice as it is frozen during the summer, and as scattering materials in rail ways. It is sometimes used to absorb liquids to allow the spill to be easily collected or apart. It was formerly common to be used in floors and/or to make Cutler's resin. Also, charcoal briquettes could be produced from saw dust [3].

The cellulose and starch which could be extracted from wood or from any other plant sources are used as filler in some low-calorie foods [4]. The cellulose that derived from saw dust is used for sausage casings [5,6]. Moreover, the cellulose derived from sawdust has also been used as filler in bread [7]. The subaltern medical staff subsisted on bread made from wild chest nuts sprinkled with sawdust [7,8].

Health hazards

The accumulation of saw and/or airborne sawdust causes some health and safety hazards [8-10]. Wood dust is a well-known human carcinogen [10-12]. Certain wood dust contains toxins that can produce severe allergy [12-14]. People exposed to wood dust are often suffering from skin and/or eye diseases due to breathing it. The permissible dose for wood dust exposure is 15 mg/m3 and 5 mg/m3 respiratory exposure over 8 hours work day. Furthermore, the recommended dose limit is 1 mg/m3 over an 8 hours work day [12-15].

Environmental hazards

At saw mills, if the sawdust does not reprocessed in particle boards, it was burned in a sawdust burner or to supply the heat for other milling operations, piles of sawdust may collect which evidently cause harmful filtrates that are creating environmental hazards [15-17]. The decay of a tree in a forest is more or less similar to the impact of sawdust, but the difference is of its rate. Saw mills may be storing thousands of cubic meters of wood residues in one place, so the issue becomes one of concentration. Several interests were taken for the lignin and fatty acids of trees, which they preserve trees from predators while they are alive, can leach into water

and poison wildlife and those may remain in the tree. The trees are usually decayed very slowly. When sawyers are processing large volumes and large concentrations of wood, the toxicity permeates into the runoff causing harmful to a broad range of organisms [14,18,19].

Objectives of the study

The main objective of the current study is an attempt to utilize the waste of sawdust in the production of light-weight high porous building bricks to avoid both environmental and health hazards of this waste product. Building bricks are clay units with standard dimensions and definite shapes subjected to firing to attain high strength which always used in the building process. The physical and mechanical properties of the prepared samples are investigated. The results are also supported and confirmed with XRD techniques and SEM micrographs. The resulting light-weight high porous building bricks are suggested to be used as isolating bricks for heat in hot countries and maybe even for cold in the cold countries.

2. EXPERIMENTAL

Raw materials

The material of oily clay used for this investigation was delivered by Aramco petroleum company, Saudi Arabia (Figure 2). The sawdust sample (Figure 1) was obtained from different local shaving factories particularly the workshop inside the National Research Centre, Egypt. About 1 kg of the samples was first dried and then crushed into lumps. The lumps were milled using universal attrition mill with alumina balls for 2 hrs. The complete homogenized milled powders were sieved using standard universal sieve 63µm. The powders with same particle sizes were shaped into disks with 2 inches diameter and 0.5 mm height. The pressing load was carried out using universal press machine into a steel die. The pressing load was fixed at 30 KN for 1 min. The samples were kept in a drier at 100 ºC for heat treatment at different temperatures.

Figure 2 The used clay sample

Characterization of the clay sample

The clay was analyzed for its vibration spectra with the aid of Fourier transform IR spectroscopy using Perkin Elmer 1800 model instrument in the range 450– 4000 cm^{-1} as potassium bromide pellet (Figure 3). XRD patterns of clay were obtained on a powder X-ray diffractometer Model Philips with Cu-Kα radiation having a scanning speed of 0·04°/s. The liquid content, humidity absorption and weight loss at 800ºC in samples were then measured. To calculate the percentage of liquid in the samples, the following law is observed. The sample was dried in an oven for 24 hours at a temperature of 100°C. The average weight of three cooled samples was taken and the total solid content is expressed as a percentage of the original weight.

Mass of liquid content in the sample, $W_4 = W_2 - W_3$ (1)

Percentage of liquid (%) = $[W_4 / (W_2 - W_1)] \times 100$ (2)

Where, W1, W2 and W3 are the weight of empty crucible, the weight sample with crucible and the weight of the dried sample with crucibler, respectively.

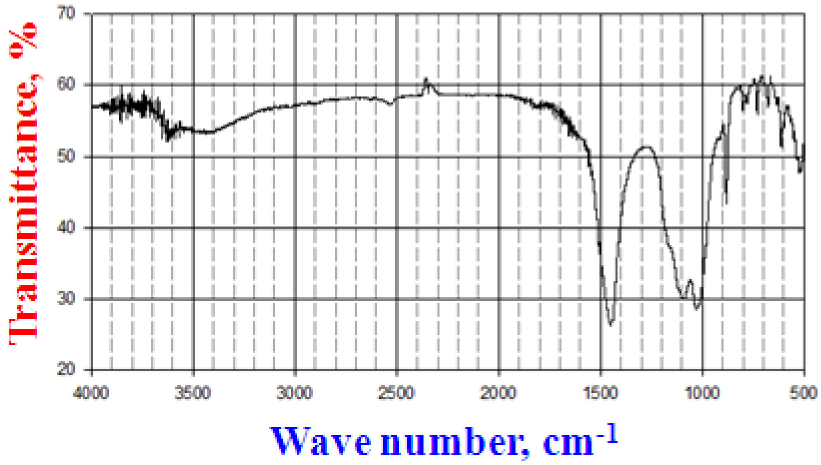

Figure 3 The FT-IR spectroscopy of Oily Clay Wastes

The material either absorbs or loses moisture as manifested by the weight gain or weight loss (Table 1). The objective is to determine the percent of moisture content (M) and the percent of the weight gain of the material as a function of time (t).

Table 1 The liquid content, humidity and weight loss of the clay, %.

No	Liquid content, %	Humidity, %	Weight Loss at 800 ° C, %
5	10.051	5.938	14.279

Constituents of raw materials

Table 2 shows the chemical analysis of the raw materials. The original ceramic base batch was composed of Clay only which was partially substituted with sawdust by 0, 4, 8, 12 and 16 wt. %.

Table 2 The chemical composition of raw materials, wt. %.

Materials / Oxides	Clay (C)	Saw dust (S.D)
L.O.I	9.72	0.84
SiO_2	53.47	72.37
Al_2O_3	26.78	5.75
Fe_2O_3	3.99	2.36
CaO	0.60	10.06
MgO	1.38	4.61
MnO	0.03	----
K_2O	1.18	0.22
Na_2O	1.15	0.18
TiO_2	1.12	----
SO_3	----	0.52
P_2O_5	0.51	0.56
Cl^-	----	----
Unknown	0.07	2.53
Total	100.00	100.00

Preparation of samples

The clay batches containing 0, 4, 8, 12 and 16 wt. % saw dust were prepared and mixed well in a roller mill for one hour using various size porcelain balls in order to obtain the same homogeneity of all batches. The batches were given the symbols B_0, B_1, B_2, B_3, and B_4, respectively. Five disc-shaped samples of 1cm diameter /1cm thickness and five slender-shaped samples of 1cm diameter / 3 cm height were cast for each batch. The molding of specimens was carried out under a shaping pressure of 20 KN/mm^2 using water as a binder. The prepared specimens were let to dry in air for 48 hours and then in a dryer at 105 ºC for another 48 hours. The firing was carried out in a slow rate furnace Mod. VECSTAR with a heating rate of 5 ºC/min. The firing temperature was ranged between 800-1000 ºC with one hour soaking time.

Methods of investigation

The 1 cm diameter / 1 cm thickness disc-shaped specimens were subjected to water absorption, bulk density and apparent porosity [20]. The 1 cm diameter / 3 cm height specimens were subjected to crushing strength [21,22]. The optimum firing temperature and the optimum batch were identified by comparison of results. The phase composition was further investigated by X-ray diffraction analysis (XRD) which was employed by a Philips X-Ray Diffractometer of Mod. P.W. 1390 with Ni-filtered Cu-Kα radiation.

3. RESULTS AND DISCUSSION

Characterization of the sawdust sample

The chemical analysis of the received starting material was carried out using the XRF technique. From Table 2, the chemical analysis of the drilling waste shows that the sample composed of highly percentage of BaO, SO_3, SiO_2, Al_2O_3, Fe_2O_3, CaO and Cl. The analysis shows a low ratio of TiO_2, Al_2O_3, and K_2O (Table 2). In addition, FTIR spectra of the oily clay waste are shown in Figure 3 in order to determine the vibration modes. The strong IR peak of Si–O stretching vibration at 1029 cm^{-1} is observed. The IR peaks at 3400 and 3600 cm^{-1} are associated with the adsorption of H_2O molecules on the clay surface. The observed peaks of 3400 and 3600 cm^{-1} are corresponding to the stretching vibrations of O–H groups.

Physical properties

The results of physical properties in terms of water absorption, bulk density and apparent porosity of the prepared ceramic bodies containing 4, 8, 12 and 16 wt. % sawdust waste are graphically represented in Figures 4-6, respectively. The results showed that as the saw dust content increased, the water absorption increased sharply. This is mainly attributed to the increase of the porosity because as the firing temperature increased the sawdust was burned completely [23-25]. This is often accompanied by the evolution of gases through the matrix of the ceramic body. As a result, the rate of porosity is evidently increased. This was reflected negatively on the bulk density, i.e. the bulk density decreased. The same trend was displayed as the soaking time increased but with lower values of water absorption and apparent porosity while higher values with bulk density [26-28].

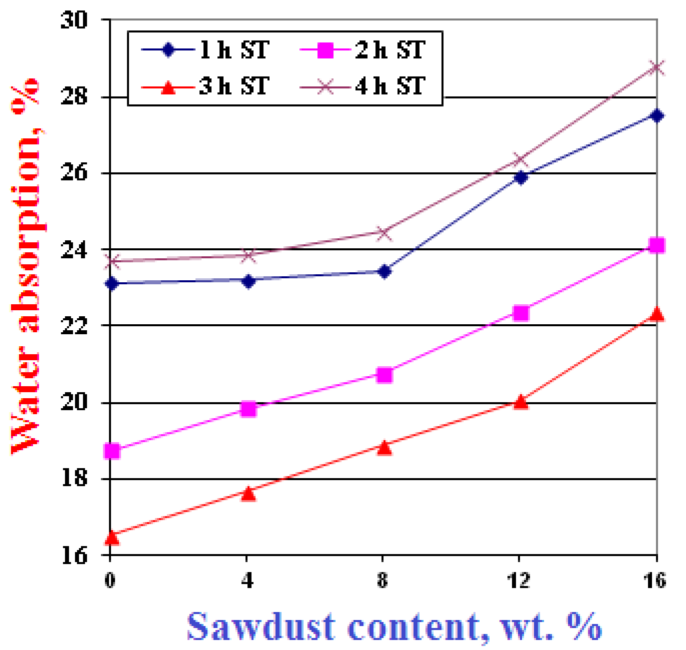

Figure 4 Water absorption of the various fired brick batches versus sawdust content

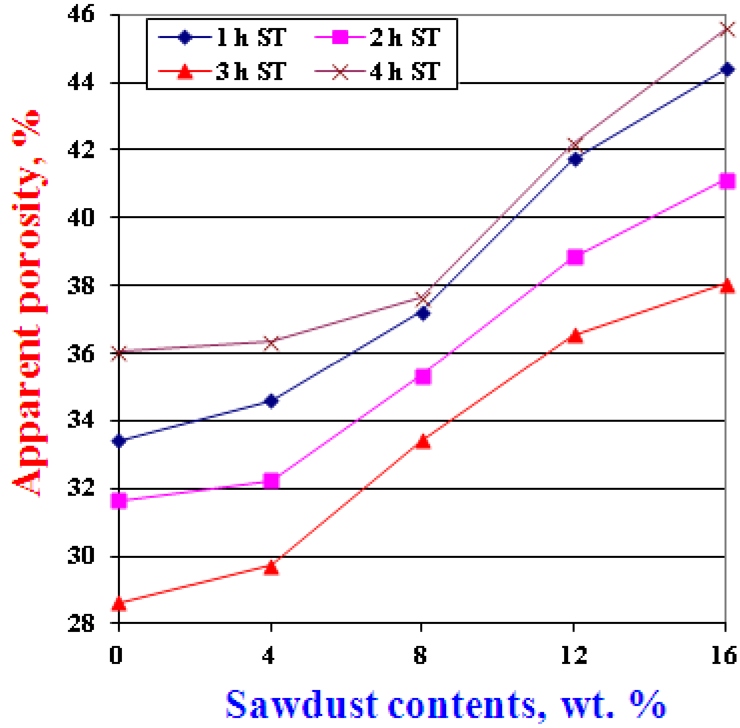

Figure 5 Apparent porosity of the various fired brick batches versus sawdust content

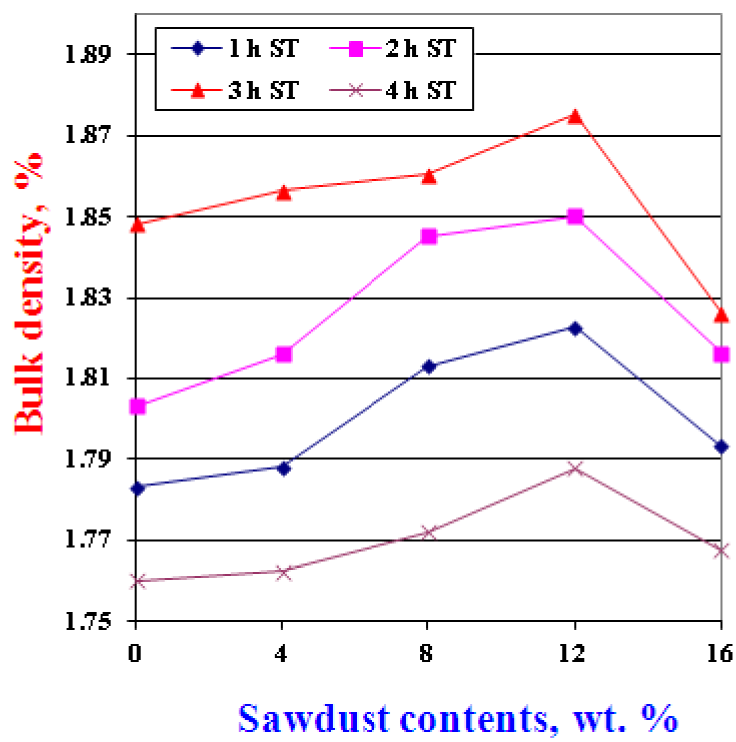

Figure 6 Bulk densities of the various fired brick batches versus sawdust content

Compressive strength

The ultimate compressive strength of the fired bodies as a function of sawdust waste content and firing temperature in terms of soaking time is shown in Figure 7. It can be observed that, for all temperatures, the compressive strength increased with the increase of sawdust addition. This is mainly due to the fact that during firing the sawdust converts to ash. This ash has pozzolanic characters

which encourage its interaction with clay constituents during firing and also after firing when contacted with water during building [23-25]. Furthermore, the ash contains microsilica which is very active and can react with the mullite phase that resulted from the conversion of the kaolinite of the clay [24]. The decreasing of the blank sintered at one hour was being noticeable. The other samples showed a gradual increase in the compressive strength values as the soaking time as well as the sawdust addition increased. As a result, it is possible to conclude that the sawdust component after its firing may be responsible for the enhancement of the mechanical strength of the fired ceramic bodies. The effect of the temperature was to increase the compressive strength by means of densification. Moreover, the results suggest a great correlation between the values of compressive strength and those of water absorption, apparent porosity and bulk density of the fired bodies [23-25]. The compressive strength was decreased with 16 wt. % sawdust content. So, the presence of more than 12 wt. % sawdust reflected negatively on the compressive strength. This may be due to that the higher amounts of sawdust acts as a hindrance between constituents to react with each other [26-28]. The same trend was displayed with at all ranges of soaking time as clearly shown in Figure 7. The results of compressive strength are in a good agreement with those obtained with water absorption, bulk density, and apparent porosity. Consequently, the optimum batch composition is that containing 12% wt. sawdust fired for 3 hours soaking time.

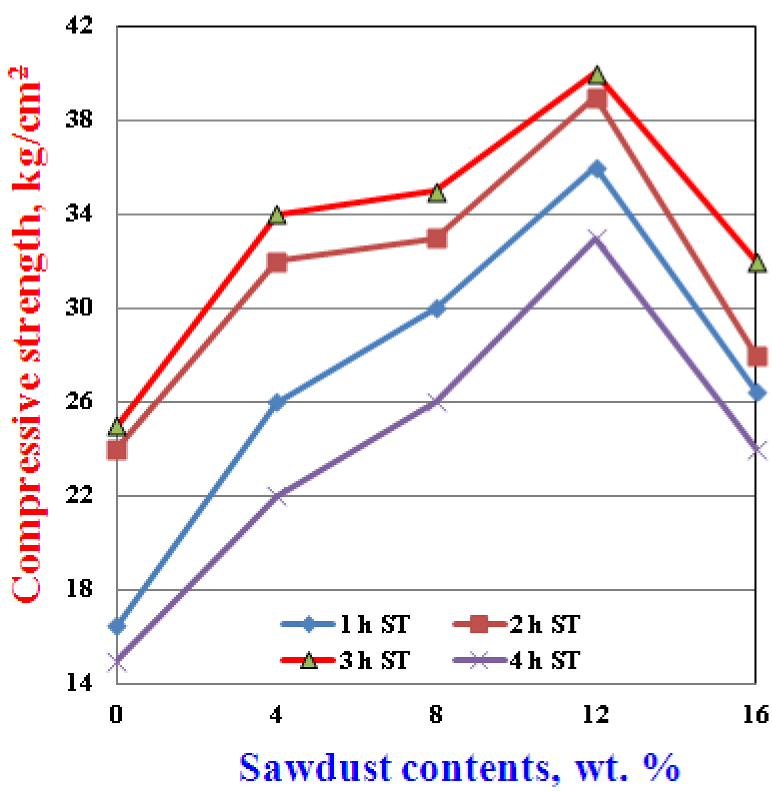

Figure 7 Compressive strength of the various fired brick batches versus sawdust content.

XRD patterns

The starting drilling waste material is mainly composed of quartz, barium sulphate in addition to calcium sulphate (Anhydrite). Figure 8 illustrates the XRD analysis for the base batch (B0) and the optimum brick batch (B3) fired at 1000 °C for 3 hours. It was observed that walstromite phase was detected ($BaCa_2Si_3O_9$ Card No: 5177). The quartz phase was detected too in the sample containing 12% wt. sawdust. These findings confirmed the chemical analysis detected before. The sawdust may delay the reaction of all silica with the barium and calcium content as compared with the blank sample.

SEM micrographs

The SEM microscopic analysis for the optimum brick batch fired at 1000 ºC for 3 hours is shown in Figure 9. The SEM of the sample has no additives fired up to 1000ºC for 3 hrs showed a large amount and volume of open pores the grains were clustered together forming cavities this may due to the low sintering temperature. Figure 9 B illustrates small columnar alumino-silicate phase gray color which may be due to the first mullite formation.

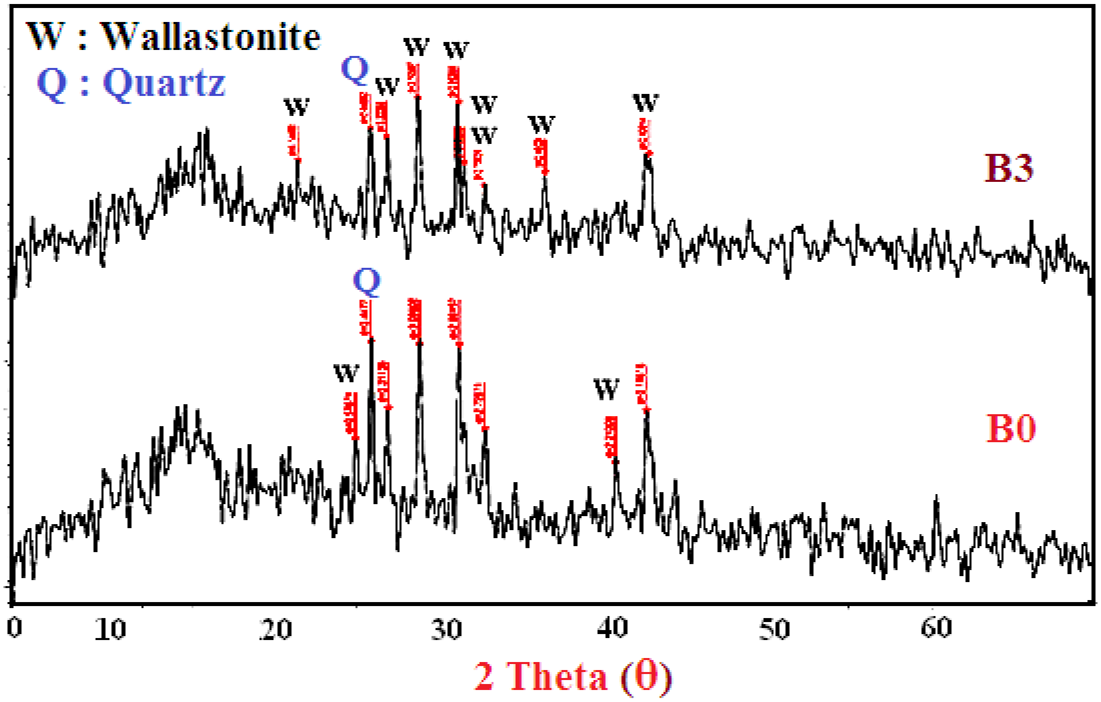

Figure 8 The XRD analysis of the base brick batch (B0) and the optimum brick batch (B3).

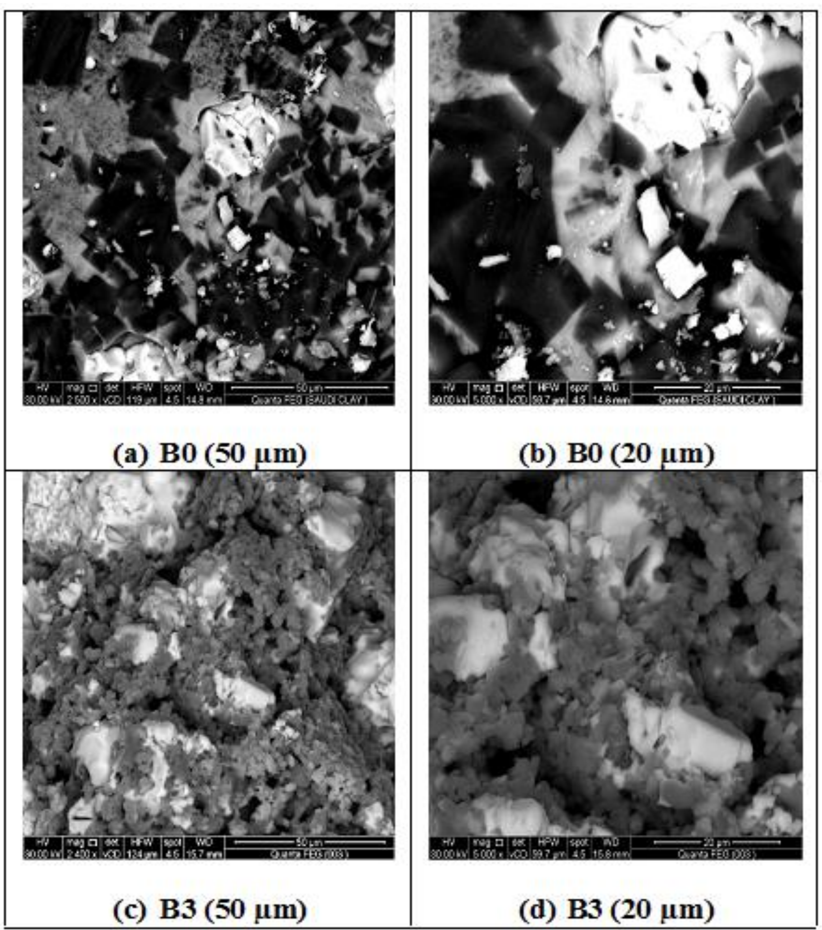

Figure 9 The SEM micrographs of the base brick batch (B0) and the optimum brick batch (B3)

The white Barium sulphate phase was impeded in the silicate phase. On the other hand, Figure 9 C showed a fully densified body with a little amount of pores and volumes. The coarse columnar alumino-silicate phase was clearly detected. The Barium sulphate phase showed some closed pores. Figure 9 D showed a large amount of silicate phases surrounded the barium sulphate. It was founded that the mode of fracture is transgranular mode which proved the enhancement of the mechanical properties.

4. CONCLUSION

The present study shows the possibility to produce Light-weight high porous building bricks with a high mechanical performance from the clay batches containing 0, 4, 8, 12 and 16%, wt. sawdust. The water absorption and apparent porosity of the prepared ceramic bodies were increased with the increasing of the sawdust content, while the bulk density was decreased. The results of compressive strength are in a good agreement with those obtained with water absorption, bulk density, and apparent porosity. Consequently, the optimum batch composition is that containing 12% wt. sawdust fired 1000 ^{o}C for 3 hours soaking times. The XRD analysis for the optimum brick batch fired at 1000 ^{0}C for 3 hours was detected walstromite phase ($BaCa_2Si_3O_9$ Card No: 5177), the quartz phase was detected too in the sample containing 12 wt.% saw dust. The SEM of the sample has no additives fired up to 1000 ^{o}C for 3 hrs showed a large amount and volume of open pores the grains were clustered together forming cavities. The resulting light-weight high porous building bricks are suggested to use as isolating bricks for heat in hot countries and maybe even for cold in the cold countries.

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Conflicts of Interest: The authors declare no conflict of interest.

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